Luzchem
Shedding light on new ideas

Spectroradiometers

Instruction manual

SPR-4001, SPR-4002 and SPR-03
Version 3.1
October 2006

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1. Initial set-up

1.1. Models SPR-4001 and SPR-03

The Spectroradiometer models SPR-4001 and SPR-03 consist of three parts:

- The control module and detection fiber
- The detection head (light integrating module)
- A USB cable

Assemble the instrument as indicated below. The connection of the blue fiber optic cable to the detector should be 'finger tight'. Do not use any tools and do not force. The calibration parameters for your instrument have been determined with the same components with which it was supplied. Individual parts are not interchangeable.

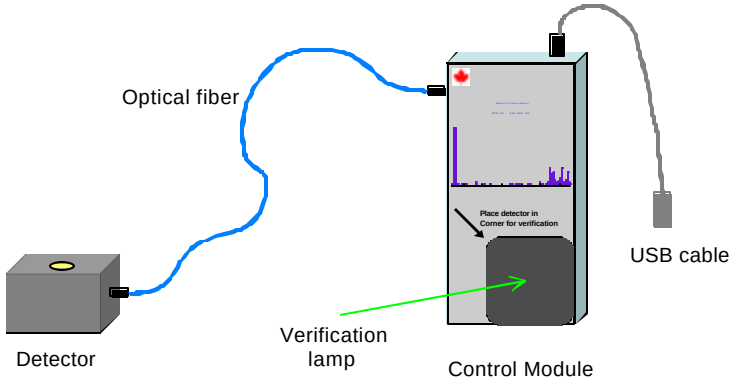


Figure 1.1: Schematic diagram for SPR-4001 and SPR-03

Optical fibers are fragile and cannot be bent at any angle. The minimum momentary bent radius is 60 mm, and the minimum long term bent radius is 100 mm (4 inches). Assemble your instrument as indicated above, and connect the USB cable to an available port in your computer. Software installation is explained in Section 3 of this manual.

1.2. Model SPR-4002

The Spectroradiometer model SPR-4002 consists of two parts:

- The control module that with its built-in detection head (light integrating module)
- A USB cable

SPR-4002 is sold fully assembled. Only the USB cable needs to be installed and connected to the computer. Software installation is explained in Section 3 of this manual.

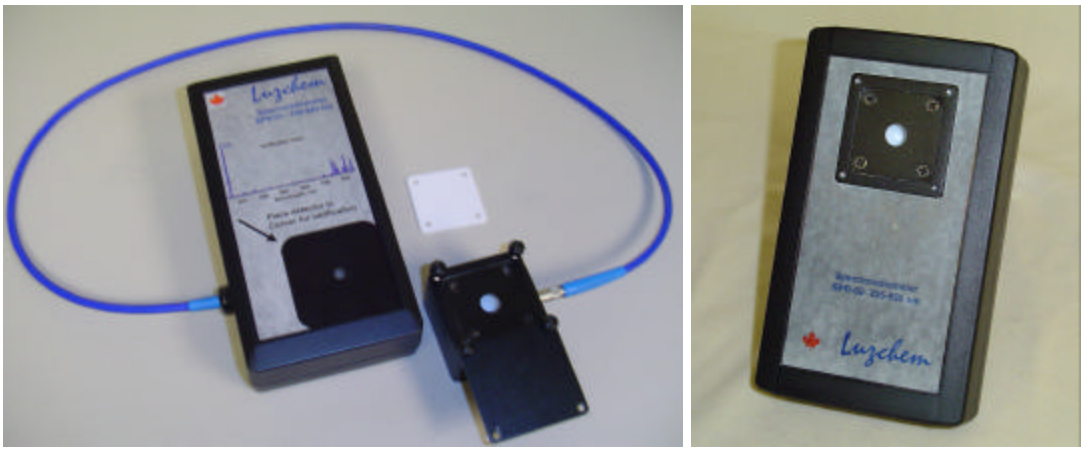


Figure 1.2: Spectroradiometer models SPR-4001 (left) and SPR-4002

2. Understand your hardware

2.1. Detector head

Figure 2.1 shows the assembly of the detector head or light integrator. The detector is constructed of PTFE encased in light scattering aluminum and has been designed for maximum efficiency in a low-profile integrator.

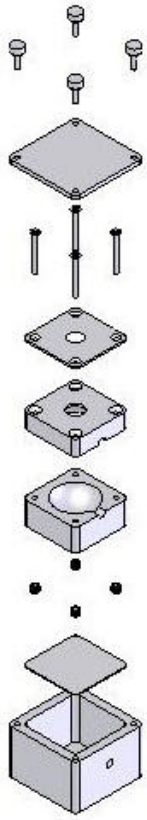


Figure 2.1: Assembly of the detector head

The top of the integrator has a solid cover that can be used when monitoring the dark background. We have found it convenient to leave one holding screw loosely in place and simply rotate the cover to monitor dark and light signals, see Figure 2.2.

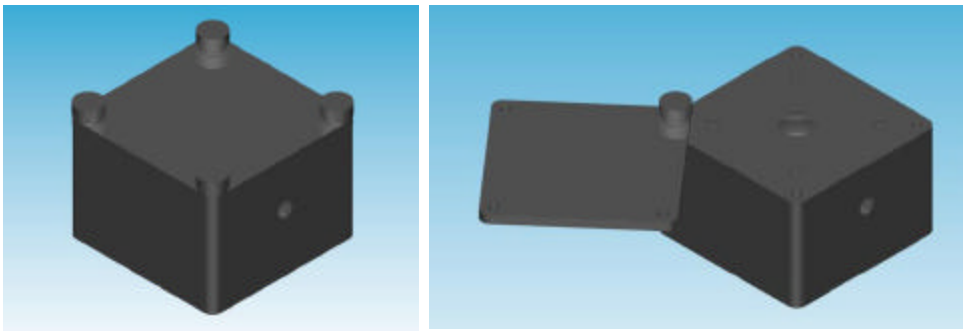


Figure 2.2: Closed and open detector assembly, as used in Model SPR-4001 and SPR-03

It is important that you do not allow dust or other materials to fall inside the detector head; this would invalidate the calibration provided by Luzchem.
The bottom of the detector head has a threaded hole (1//4-20 threads) that can be used for mounting the detector. A very thin aluminum plate protects the PTFE compartment from damage by objects inserted through the mounting hole. The maximum penetration is 3 mm. Do not force screws to penetrate more than this, since they can damage the integrator compartment.

2.2. Spectrometer

The heart of Luzchem spectroradiometers is a 3648 element spectrometer contained in the control module. It covers a minimum range of 235 to 850 nm in the SPR-4001 and SPR-4002, a minimum range of 235 to 1050 nm in the SPR-03 and has optical components to optimize ultraviolet detection. Data points are acquired about every ~0.3 nm; however the software converts the data so that points are displayed at 1 nm intervals.
The spectrometer is quite robust and ideal for field work and wherever portability is important. However, it should be protected for water and high temperatures.
Stray light is quite low, for example: < 0.05% at 600 nm, < 0.10% at 435 nm, and < 0.10% at 250 nm. The grating used has 600 lines/mm and has been blazed at 400 nm.
Spectrometer control is achieved via the USB port; no other source of power is required to operate the spectrometer.

2.3. Fiber optic cable

The fiber optic cable, connecting the spectrometer to the detector head is an integral part of your instrument (it is fully enclosed in the spectroradiometer model SPR-4002), and instrument calibration is dependent on the fiber used.
The fibers used are terminated with SMA connectors that have been carefully polished to achieve adequate optical performance. Luzchem uses high-OH fibers to optimize ultraviolet performance. For model SPR-4001 the fiber used is 300 μm in diameter and the SPR-03 uses a 750μm solarized fiber. The minimum allowed momentary radius is 60 mm (~2.5 inches), and the minimum long term radius is 100 mm (4 inches). Bending the fiber beyond these limits can cause permanent damage that also invalidates the calibration factors. Fiber replacement requires recalibration of the instrument.

Instructions for SPR-4001 and SPR-03

When installing the fiber, the connection should be "finger tight". Do not use tools for this purpose.
The female SMA connector on the detector head should not move when installing or disconnecting the fiber. It has been installed with a special adhesive that under normal force conditions will prevent the female connector on the detector head from moving. If this connector moves it will be necessary to reinstall it matching exactly the calibration distance. Contact Luzchem for assistance.

2.4. Attenuator

Luzchem spectroradiometers are supplied with a PTFE film attenuator that reduces the light input by about one order of magnitude. A generic transmission curve is supplied with all attenuators.
Luzchem can perform a custom NIST traceable calibration for the attenuator supplied with the system. For many applications the attenuator is not essential; however, for some solar and sunbed applications, the attenuator may be useful to increase the dynamic range of the instrument.

2.5. Verification lamp (model SPR-4001 and SPR-03)

Model SPR-4001 and SPR-03 includes a low pressure mercury lamp that operates with 4 AA batteries. The lamp is controlled by a switch at the back of the instrument. This switch does not need to be on to operate the radiometer, but only to use the verification lamp. The verification lamp has the spectrum of Figure 2.3 (this is a power spectrum), with a characteristic band at 254 nm that should be within ±1 nm of the wavelength read.

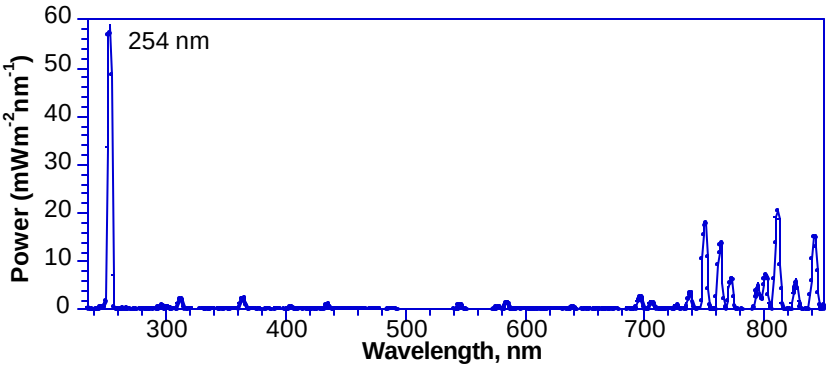


Figure 2.3. Power spectrum for the verification lamp.

The correct positioning of the detector on the verification lamp is illustrated in Figure 2.4. In addition to verification of the wavelength, the verification lamp is useful in determining the integrity of the optical fiber. Typically the intensity (that is, before conversion to a power spectrum) should be between and 50 and 150 counts at 254 nm for an integration time of 1000 ms.

Figure 2.4. Positioning of the detector head on the verification lamp.

If the counts at 254 nm are significantly less than 50, change the batteries (alkaline batteries are recommended). If the problem is not resolved by this, it could be an indication of a ruptured fiber; in this case, contact Luzchem for advice. Lamp usage for verification purposes normally does not exceed a few minutes, and batteries last about 12 hours of actual usage. Figure 2.5 shows a representative discharge curve under continuous operation.

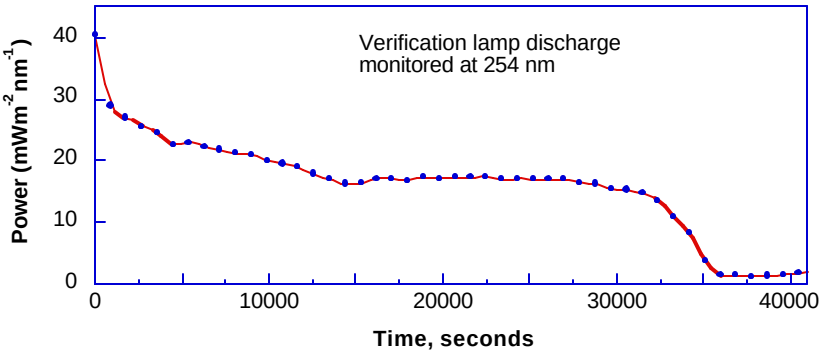


Figure 2.5. Verification lamp discharge curve monitored at 254 nm.

3. Software Instruction manual

3.1 General

The purpose of this Section is to provide training on the acquisition and viewing of spectra. This application can acquire information at timed intervals ranging from 1/10 of a second to hours. In order to establish the best possible integration time, the spectroradiometer application is equipped with an "Optimize Integration Time" function. This function searches for the best integration time for the intensity of the incident light.

In order for the spectroradiometer application to be able to acquire data, it needs to be connected to the spectroradiometer instrumentation. However, it can be used independently to view previously acquired files. The application also requires that the LabVIEW *run time engine* be loaded in the computer in use. The LabVIEW run time engine is provided in the installation package.

3.2 Software Installation

3.2.1 Ensure the latest Java Runtime Environment (JRE) is installed on your computer. Available for free from Sun Microsystems at http://java.sun.com/javase/downloads/index.jsp

3.2.2 Insert the SPR installation CD into your CD-ROM drive.

3.2.3 Navigate to your CD using "My Computer"

3.2.4 Select the "Installer" folder and then "Setup"

3.2.5 Follow the installation instructions.

3.3 Connecting the hardware

3.3.1 Connect the USB cable from the spectroradiometer to your computer.

3.3.2 Your computer should detect the new hardware and find the drivers automatically. If not, go to Control Panel > Add or Remove Hardware. Then install the hardware by searching for drivers on the CD provided with the spectroradiometer.

3.4 Starting the software

3.4.1 Ensure your Luzchem spectroradiometer is connected to your computer. Please note that the application is only compatible with the spectrometers sold by Luzchem. If the software does not recognize the spectrometer, it will give an error message and close.

3.4.2 To start the spectroradiometer application, select the application in the Program Files folder. To create a shortcut on the desktop right click on the application and select "Send to>Desktop (create shortcut)".

3.4.3 The first time you run the spectroradiometer software, a 'Configure Hardware' window will appear (see figure 3.1 below). Select the following values in the drop-down menus:

Spectrometer Type: S4000

A/D Converter Type: USB4000 (SPR-4001 and SPR-4002)

HR4000 (SPR-03)

If your version of the software displays a Serial Number dialog, ensure your spectrometer serial number is highlighted (usually located at the bottom of the list).

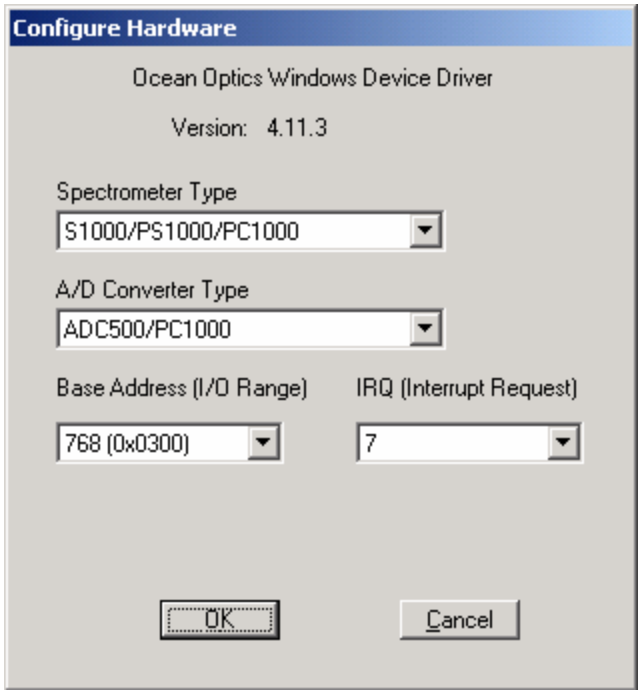


Figure 3.1: Configure Hardware window

3.5 Optimize Integration Time

The optimize integration time function tests the intensity of the light and searches for an appropriate integration time. This function is important because if the integration time is too short, the data is susceptible to errors introduced by noise. If the integration time is too long, the spectrometer can saturate, and the data above the saturation point will be a flat line. For the SPR-4001 and SPR-4002 the spectrometer saturation level is approximately 65000 counts. The SPR-03 saturation level is approximately 16000 counts.

3.4.1 Navigate to the "Start Optimize Integration" tab

3.4.2 Press the "Start Optimize" button

3.4.3 Turn on the light and press "Start Optimize". Note that the optimize function does not require a dark measurement.

3.4.4 The application will test different integration times in order to find the best one. Once the optimization is done, a dialog box will inform the user of the optimized integration time. If the integration time is less than 1 or greater than 1000, a warning message will appear.

3.4.5 If the optimized integration time falls in an acceptable range, all integration times in the program will be set to this value. The user can override these values.

3.4.6 If the signal saturates at 1 ms integration time the use of an attenuator is highly recommended (See section 2.4).

3.5 Power/Intensity Spectra

Power or intensity spectra can be acquired alone, or extracted from a timed acquisition file. This section will cover acquiring a spectrum by itself.

> ***Definitions****: An intensity spectrum is a plot of counts against wavelength; it shows the raw data acquired by the detector; it does not use energy units. A power spectrum shows the energy distribution as a function of wavelength; the Luzchem system displays this in units of mW* m^{-2} nm^{-1}*. An intensity spectrum can be converted to a power spectrum by using a calibration file.*

3.5.1 If desired, optimize integration time by following steps above.

3.5.2 Navigate to the "Spectroradiometer" tab.

3.5.3 Acquire a dark reference by turning off the source lamp or by blocking the light input.

3.5.4 Open the light input window and acquire a sample.

3.5.5 Note that the data that is viewed on the acquisition graph can be changed by using the radio buttons beneath the graph:

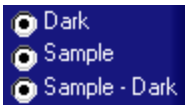


Figure 3.2: Radio buttons select the sets of data displayed

3.5.6 To create a power spectrum from the desired data, an appropriate calibration file must be chosen. To use Luzchem's calibration file, select "Use Luzchem's Supplied Calibration" from the calibration drop-down menu. If this option is not available, it mean that the spectroradiometer serial number that is attached does not match the calibration serial number.

3.5.7 To use your own calibration file, select "Use calibration from File" and then press the "Browse" button or type in the path to the calibration file:

Figure 3.3: Selection of a calibration file other than the Luzchem file built into the control software.

3.5.8 The calibration file must be a per-millisecond text file with the following format:

- Line 1: "Calibration Merge File"
- Line 2-4: Information you wish to save
- Line 5: Minimum Wavelength (tab) Maximum Wavelength
- Line 6 – 11: Information you wish to save
- Line 12: Wavelength w1 (tab) Calibration at w1
- Line 13…: Wavelength w2 (tab) Calibration at w2
- A one nm wavelength interval is required. Also, a calibration wavelength should exist for each wavelength in the acquisition. If a desired wavelength does not exist in the calibration file, the resulting waveform will produce a zero at that wavelength.

3.5.9 Once the calibration file has been chosen press the "Power Spectra" button. A power spectrum will then appear on the Display graph. On the left is the power (mW/m^2) in the UVA, UVB, UVC, Visible, and user-selected spectrum (Figure 3.4). These spectra can be viewed on the display graph by checking the radio buttons to the left of the numbers (Figure 3.5).

Figure 3.4: Definition of a customer-selected integration range

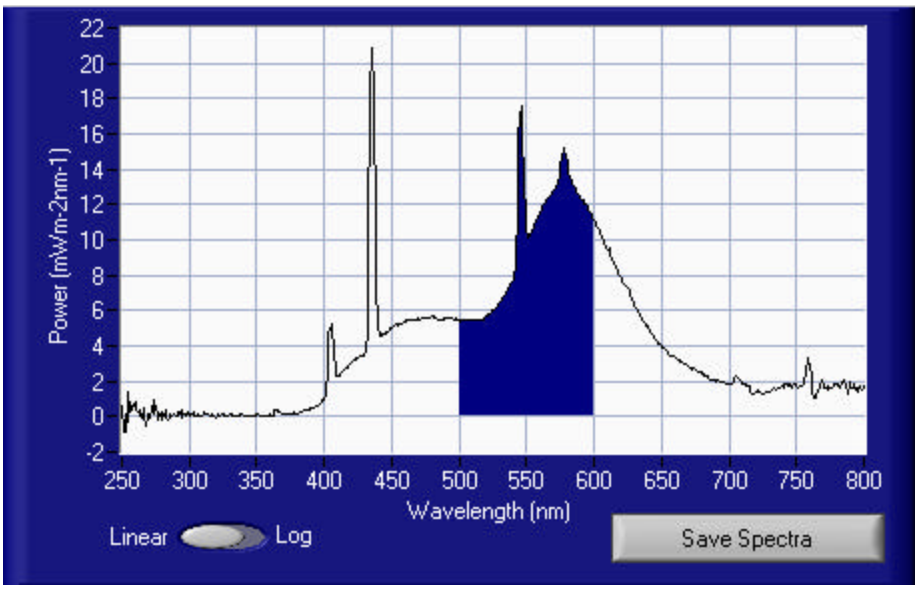


Figure 3.5: Shaded display of a selected integration range.

3.5.10 Luminance (lux) and Color Temperature (K) are also displayed below the user selectable power spectrum controls.

3.5.11 Intensity spectra can be created using the "Intensity Spectra" button. This will transfer the data from the acquisition graph to the display graph where it can be saved. UVA, UVB, UVC, visible spectra, luminance, and color temperature cannot be viewed.

3.5.12 To save the spectrum press the "Save Spectra" button located below the graph. This will save the graph in a tab delimited text file that can easily be opened with most spreadsheet and graphing applications. (Please see the "File Format" section for the formatting of the intensity/power file.)

3.5.13 Once the spectrum is saved it can be opened at any time by using the "Read File" button. An intensity spectrum can be opened and converted to a power spectrum. In this case it is essential to use the calibration file applicable at the time of acquisition.

3.6 Data reliability evaluation

A switch on the left lower main screen allows this option to be turned on and off. The default as the program starts is ON. Figure 3.6 shows this control.

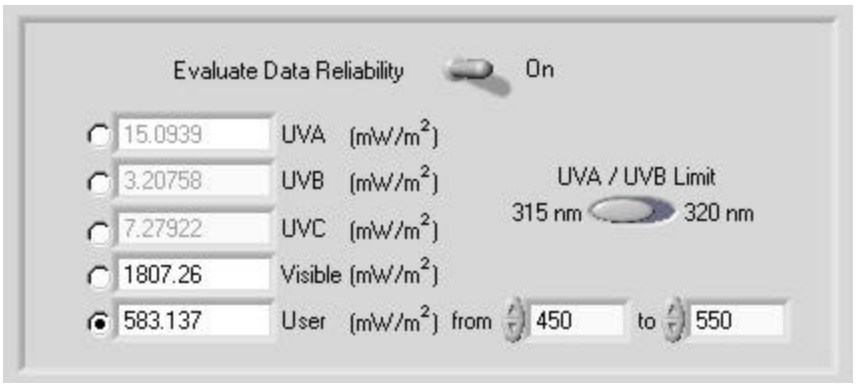


Figure 3.6: Data reliability evaluation turned on. Note 'gray' values when the criterion set in the optimize tab is not met.

The data are shown in grey when they do not meet the significance criterion set in the optimize tab. If should be noted that Luzchem sets a very high standard as a default; users should set values that meet their own requirements. This is done in the "Optimize" tab, where you will find in the left region the menu of Figure 3.7. You have three options:

- An ON/OFF switch serves the same function as that on the main window.
- The percent of the data that must meet the criterion.
- The number of counts below which the data is judged unreliable.

Note that when the data is labeled as unreliable, it only means that the numeric value posted in the front window may have considerable error; however, in general it is a good assumption that for practical purposes the value is very small or zero.

In regions where there is essentially no light, one expects points with very small values showing a random distribution around zero; *i.e.*, 50% of the values could be negative. This is normal. To improve the data increase the number of averages, increase the integration time, and ensure that the dark measurement totally prevents light from reaching the detector.

In the UVC region it is possible that some light sources or materials eliminate all light at the short wavelength range, such as wavelengths below 250 nm. While the instrument range is 235 to 850 nm for the SPR-4001 and SPR-4002 or 235 to 1050 nm for the SPR-03, you may want to reduce the range to one that is more appropriate to your own light sources. You can do this in the main screen.

Figure 3.7: Data reliability evaluation turned on. Two controls set the criterion for data evaluation.

3.7 Timed Acquisition

The timed acquisition tab is very useful if you wish to see how the intensity of a lamp or light source changes over time. It is very important to check your power management options before performing a timed acquisition that will be left alone for long periods of time. To turn off standby or hibernation :

- Navigate to Start>Settings> Control Panel
- Click on the Power Management icon
- Set system standby to "Never"
- Set hibernation to "Never" – Please be aware that some operating system will not have a hibernation option.
- Click "Apply" and/or "OK" to save the settings and exit the power management window.

To perform a timed acquisition:

3.7.1 If desired, optimize the integration time by following the steps outlined in the Optimize Integration Time section. Note that the detector will saturate if the intensity increases by more than 60% during the timed acquisition. Use a shorter integration time if this is likely.

3.7.2 Press on the "Timed Acquisition" tab

3.7.3 Set the acquisition interval and total acquisition time (see Figure 3.8).

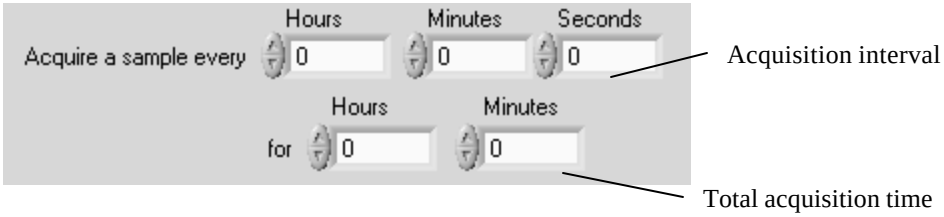


Figure 3.8: Selection of parameters for a timed acquisition

3.7.4 The Total acquisition time must be greater than or equal to the acquisition interval. If this condition is not satisfied, an error message will appear and the acquisition will be cancelled (Figure 3.9).

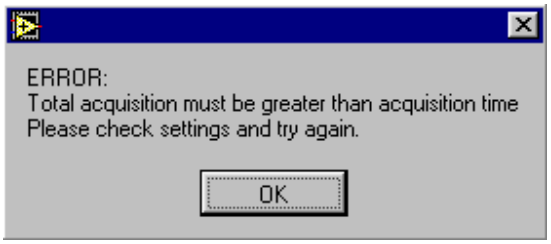


Figure 3.9: Error message following selection of incompatible parameters for a timed acquisition.

3.7.5 If (integration time + transmission delay)*number of samples is greater than the acquisition interval, an error will occur. In this case, either the integration time or the number of samples to average must be decreased so that (integration time + transmission delay)*number of samples is less that the acquisition interval. Transmission delay is approximately 12 ms.

3.7.6 The acquisition interval can be as low as 0.1 seconds. Any lower and an error message will appear.

3.7.7 When all parameters are set, press the "Start Timed Acquisition" button.

3.7.8 If the acquisition interval is less than 1 second, the top graph will not be updated as the acquisition occurs. This is to save processor resources. However, if the interval is greater than or equal to one second, the top graph will be updated at each acquisition. The current time can be viewed in the box in the bottom left hand side of the graph.

3.7.9 If the acquisition interval is equal to or greater than 10 seconds, a timer will appear in the bottom left of the graph, counting down the seconds to the next acquisition.

3.7.10 The acquisition can be stopped at any time by pressing the "Stop Timed Acquisition" button.

3.7.11 When the acquisition is finished, a dialog box will appear and ask you whether you would like to save the current timed acquisition. If you wish to save, press yes, if you do not wish to save, press no. The acquisition can be saved later. Timed acquisition files can be quite large and may take a few seconds to load and save.

3.7.12 In order to extract a kinetic trace, choose a wavelength on the bottom left-hand side of the screen. Next, press "Save Kinetic Trace". The line of information will be saved with the file.

3.7.13 In order to extract a spectrum from the timed acquisition, choose the time at which you wish to extract the spectrum. Next, press "Save Spectrum". The line of information will be saved with the file. The file will also be transferred to the "Spectroradiometer" tab where it can be edited and manipulated.

3.7.14 The entire timed acquisition can be converted to a power file. This can be done by choosing an appropriate calibration file. (Either Luzchem's supplied calibration, or a user calibration file.) Next, press the "Convert to Power" button to calibrate all of the data.

3.7.15 For file formats please see the "File Formats" section.

3.8 File Formats

The spectroradiometer saves four types of files: spectrum files, timed acquisition files, kinetic traces, and spectrum files extracted from a timed acquisition. Below is a summary of the information contained in each file:

3.8.1 Spectrum/Power File:

Line 1	"Spectroradiometer" (tab) "Intensity" / "Power" (depending on spectrum type saved)
Line 2	Integration time (tab) Samples to average
Line3	Minimum wavelength (tab) Maximum wavelength
Line 4	Line of information
Line 5	Serial number of spectrometer
Line 6-9	
Line 10	"Wavelength" (tab) "Intensity" (tab) "Power"
Line 11	Wavelength w1 (tab) Intensity data at w1 (tab) Power data at w1 (if applicable)

Line 12…	Wavelength w2 (tab) Intensity data at w2 (tab) Power data at w2 (if applicable)

In an intensity file the column for 'power data' will be blank.

3.8.2 Timed acquisition file:

Line 1	"Spectroradiometer – Timed Acquisition"
Line2	"Intensity" / "Power"
Line 3	Integration time (tab) Samples to Average
Line 4	Minimum wavelength (tab) Maximum wavelength
Line 5	Line of information
Line 6	Serial number of spectrometer
Line 7-9	
Line 10	Wavelength array separated by tabs
Line 11	Time array separated by tabs
Line 12	Spectrum at time t1 separated by tabs
Line 13…	Spectrum at time t2 separated by tabs

3.8.3 Kinetic Trace:

Line 1	"Spectroradiometer – Kinetic"
Line 2	Wavelength at which the kinetic trace was taken
Line 3	Line of information
Line 4	Serial number of spectrometer
Line 4	Time per point (sec)
Line 6-11	
Line 12	"Time" (tab) "Power" / "Intensity"
Line 13	Time t1 (tab) power/intensity at t1
Line 14…	Time t2 (tab) power/intensity at t2

3.8.4 Spectrum extracted from timed acquisition:

Line 1	"Spectroradiometer - Spectrum" (tab) "Intensity" / "Power" (depending on the type of spectrum saved)
Line 2	Integration time (tab) Samples to average
Line 3	Minimum wavelength (tab) Maximum wavelength
Line 4	Line of information
Line 5	Serial number of spectrometer
Line 6-8	
Line 10	"Spectrum at time:" time at which spectrum was extracted
Line 11	"Wavelength" (tab) "Intensity" (tab) "Power"
Line 12	Wavelength w1 (tab) Intensity at w1 (tab) Power at w1 (if applicable)
Line 13…	Wavelength w2 (tab) Intensity at w2 (tab) Power at w2 (if applicable)

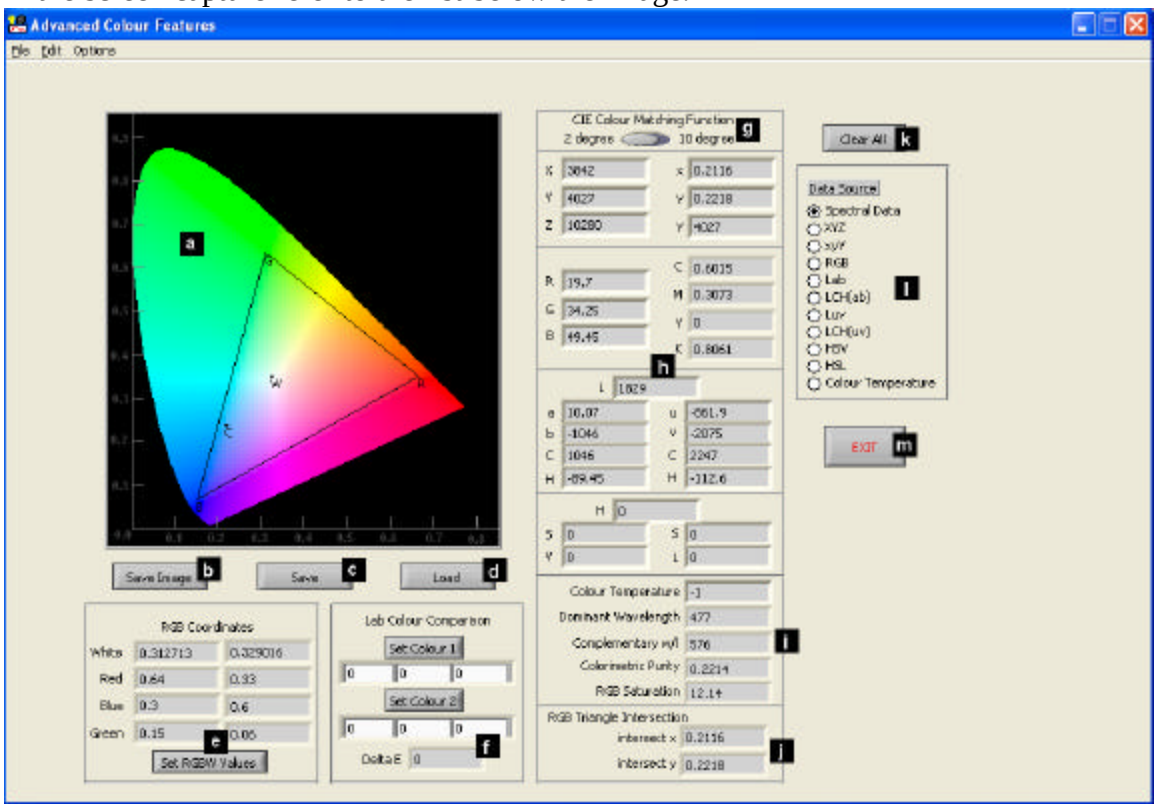
4. Help

To access the in-program help, click on the “Help” button, or navigate to **Help > Topic Help** on the menu bar.

5. Advanced Colour Features

The Advanced Colour features can be accessed by clicking the ‘Colour Advanced’ button on the ‘Spectroradiometer’ tab. These features are for users that would like a more in depth analysis of the colour properties of their light source. If a power spectrum has been produced with the spectroradiometer, the program will use the current power spectrum as the default values for evaluation. Additional power spectrums can be loaded and evaluated from the Advanced Colour window. In addition to spectral analysis, the dialog can evaluate colour data gathered from a variety of sources.

Advanced Colour Diagram Screen Capture : For details about the individual components of the dialog, the numbers (black square containing white letters) displayed in the screen capture refer to the list below the image.



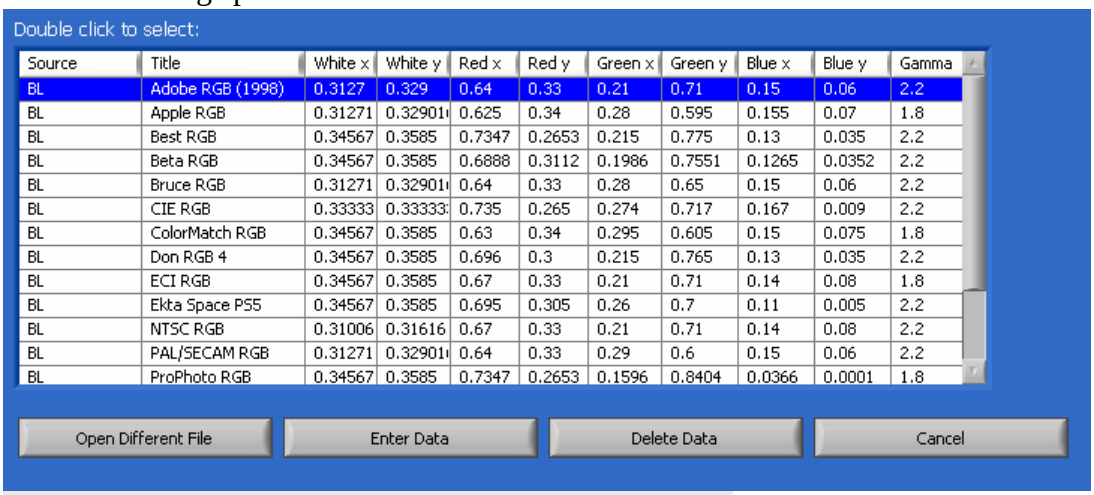
a. 1931 CIE Colour Diagram: displays RGB triangle, white point and user-defined point (via spectrum or right panel). When the user-defined point is outside the RGB triangle, the line connecting the user point and the white point is displayed.

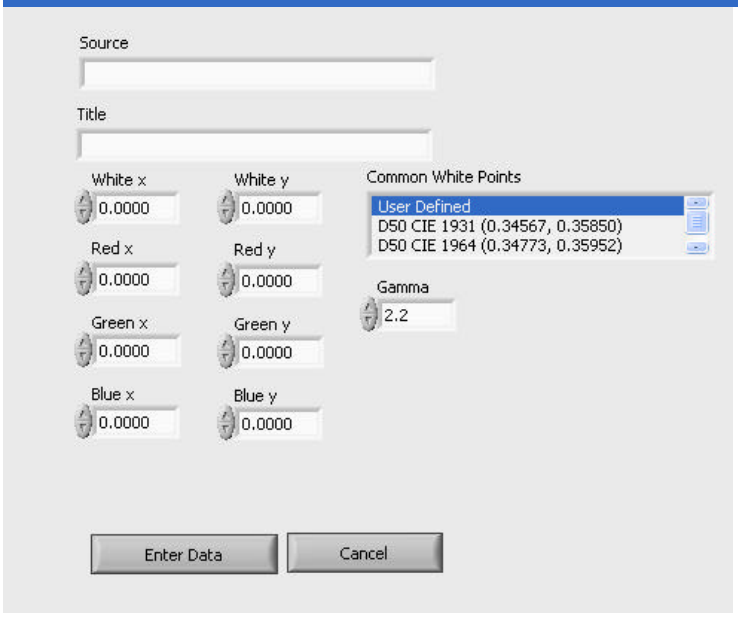
b. Save Image: Image can be saved in .BMP, .JPG or .PNG format

c. Save: Colour data can be saved in a .txt file.

d. Load: LUZCHEM power spectrum files can be loaded for analysis.

e. RGB Coordinates: The (x, y) chromacity diagram coordinates of each colour are displayed. Clicking the 'Set RGBW Values' button opens a dialog wherein different values for RGB and White Point can be set. They can be selected from numerous existing RGB values (more than 15, including Adobe RGB, Beta RGB, ColorMatch, CIE, sRGB) and white points (more than 25, including 1931-D50, 1964-D50, 1931-D65, and 1964-D65) or user-defined working spaces can be defined and saved. sRGB is the default.





f. Colour Comparison: ? E is calculated using the two colours L*a*b* values.

g. CIE Colour Matching Function: Either 2 or 10 degree colour matching functions can be used for evaluation of spectral data.

h. Colour Values: Common colour values are calculated and displayed based on the data source selected. Data can only be entered in fields with a white background. Available values: Spectral Data, XYZ, RGB, xyY, Lab, LCH(ab), Luv, LCH(uv), HSV, HSL and Colour Temperature. Fields appear greyed out if they can not be computed, or they are

subject to significant error. CMYK, HSV and HSL values are all set to zero if any RGB value is outside the range (0, 255).

i. Additional Data: Dominant wavelength, complementary wavelength, XYZ colorimetric purity and RGB saturation are calculated and displayed. Fields appear greyed out if they can not be computed, or they are subject to significant error. Additionally, dominant and complementary wavelength will display 'NaN' and appear greyed out if they lie on the purple line.

j. RGB Triangle Intersection: The intersection of the RGB triangle and the line formed by connecting the white point and the user-defined colour (displayed on the Colour Diagram). If the user-defined point is inside the triangle, its intersection is itself.

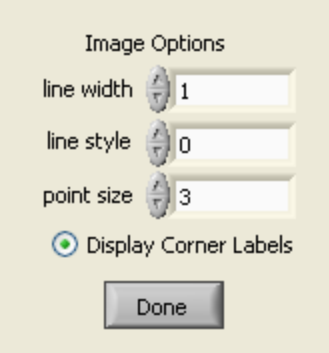
k. Clear All: All colour values can be cleared.

l. Data Source: Users can compute all colour values from one colour value source of their choosing. Enabling a data source will disable all other entry fields.

m. Exit: Quit the Advanced Colour Features Dialog.

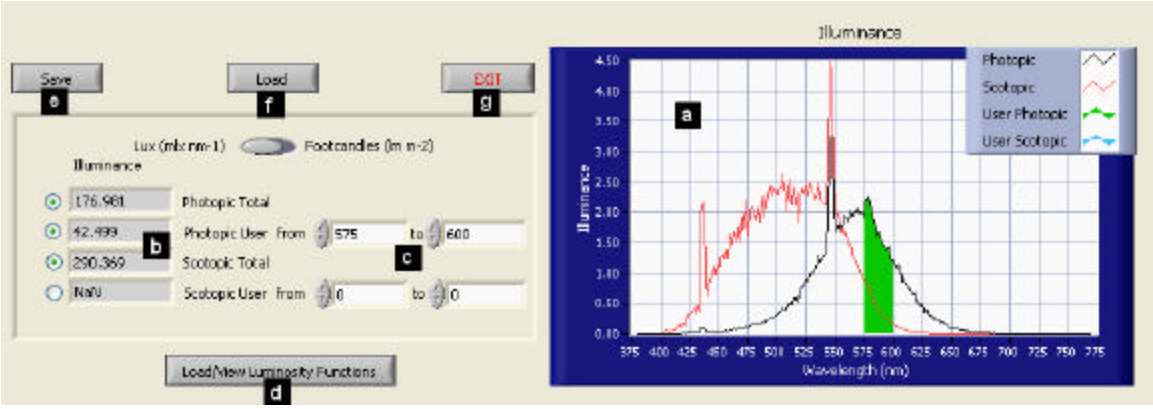
Options Menu

Image Options: A dialog is opened wherein display options can be defined for the Chromacity Diagram. (See diagram below)



6. Advanced Illuminance

The Advanced Illuminance features can be accessed by clicking the 'Illumination Advanced' button on the 'Spectroradiometer' tab. These features are for users that would like a more in depth analysis of illuminance. Default options or user preferences can be used for all calculations and display. If a power spectrum has been produced with the spectroradiometer, the program will use the current power spectrum as the default values for evaluation. Additional power spectrums can be loaded and evaluated from the Advanced Illuminance window.



a. Graph: Illuminance Graph displays photopic and scotopic illuminance. User specified ranges appear as solid colours on the graph.

b. Total Illuminance: The total integrated photopic and scotopic illuminance is displayed, as well as the total illuminance in the user-defined range.

c. User Range: Enter a wavelength range for analysis. The total illuminance for that range will be calculated and displayed. The specified range will appear as a solid colour on the Illuminance graph.

d. Load/View Luminosity Functions: Standard Luminosity Functions can be viewed numerically and graphically. Luminosity functions to be used for evaluation can be selected from a list or loaded from user-defined files.

User-defined Luminosity Function File Format

Line 1: Line of information

Line 2 and on: number pairs separated by tabs– (wavelength, V(?))

Sample File:

```
Photopic Luminous Efficiency – CIE 1988
380	0.0005890000
381	0.0006650000
382	0.0007520000
383	0.0008540000
```

384	0.0009720000
385	0.0011080000
386	0.0012680000
387	0.0014530000
388	0.0016680000
389	0.0019180000
390	0.0022090000

e. Save: File is saved in tab-delimited format so it can easily be inserted into a spreadsheet.

Save File Format:

Line 1:
Line 2:
Line 3:
Line 4:
Line 5:
Line 6: Timestamp: Date and Time of Save
Line 7:
Line 8: Total Photopic Illuminance
Line 9: Total Scotopic Illuminance
Line 10:
Line 11: Wavelength Photopic Scotopic
Line 12(and on): tab-separated values associated with the column headers from line 11

f. Load: previously acquired LUZCHEM power spectrum files can be loaded for analysis.

g. Exit: Quit the Advanced Illuminance Features Dialog.

Appendix A: Advanced Colour Features Technical Specifications

Overview
This section provides the formulas and data used to calculate values in the advanced Colour Features dialog included with LUZCHEM's Spectroradiometer software.

Conversions

Colour Temperature to xyY [8]

$$x = \begin{cases} \frac{-4.6070 * 10^9}{T^3} + \frac{2.9678 * 10^6}{T^2} + \frac{0.09911 * 10^3}{T} + 0.244063 & 4000 <= T <= 7000 \\ \frac{-2.0064 * 10^9}{T^3} + \frac{1.9018 * 10^6}{T^2} + \frac{0.24748 * 10^3}{T} + 0.237040 & 7000 < T <= 25\,000 \end{cases}$$

x is inaccurate if T < 4000 or T > 25 000 so the colour fields will appear greyed out. When T < 4000, the first formula is used and when T > 25 000 the second formula is used.

$y = -3.000x^2 + 2.870x - 0.275$

Computing [M] [8]

Used for RGB to XYZ and XYZ to RGB conversions

$$[M] = \begin{bmatrix} S_r X_r & S_r Y_r & S_r Z_r \\ S_g X_g & S_g Y_g & S_g Z_g \\ S_b X_b & S_b Y_b & S_b Z_b \end{bmatrix}$$

for each colour, C, in {R, G, B, W}

$X_c = x_c / y_c$
$Y_c = 1$
$Z_c = (1 - x_c - y_c)/y_c$

$$[S_r \quad S_g \quad S_b] = [X_w \quad Y_w \quad Z_w] \begin{bmatrix} X_r & Y_r & Z_r \\ X_g & Y_g & Z_g \\ X_b & Y_b & Z_b \end{bmatrix}^{-1}$$

HSL to RGB [4]

$$temp2 = \begin{cases} L * (1.0 + S) & L < 0.5 \\ L + S - (L*S) & L \geq 0.5 \end{cases}$$

$H_k = H/360$
$temp3_R = H_k + 1/3$
$temp3_G = H_k$
$temp3_B = H_k - 1/3$

for each colour, C, in {R, G, B}

$$temp3_C = \begin{cases} temp3_C + 1.0 & temp3_C < 0 \\ temp3_C - 1.0 & temp3_C > 1 \end{cases}$$

$$C = \begin{cases} temp1 + (temp2 - temp1)*6.0*temp3_C & temp3_C < 1/6 \\ temp2 & 1/6 \le temp3_C < 1/2 \\ temp1 + (temp2 - temp1)*6.0*(2/3 - temp3_C) & 1/2 \le temp3_C < 2/3 \\ temp1 & temp3_C \ge 2/3 \end{cases}$$

HSV to RGB [3, 12]

Hi = floor(H/60) % 6
f = H/60 – Hi
p = V(1-S)
q = V(1 – f * s)
t = V(1 – (1-f) * S)

case: Hi = 0, then R = V, G = t, B = p
case: Hi = 1, then R = q, G = V, B = p
case: Hi = 2, then R = p, G = V, B = t
case: Hi = 3, then R = p, G = q, B = V
case: Hi = 4, then R = t, G = p, B = V
case: Hi = 5, then R = V, G = p, B = q

Lab to XYZ [8]

for each D in {X, Y, Z} and d in {x, y, z}

$D = dD_w$

$$d = \begin{cases} f_d^3 & f_d^3 > \varepsilon \\ (116 f_d - 16)/\kappa & f_d^3 \le \varepsilon \end{cases}$$

$$y = \begin{cases} ((L + 16)/116)^3 & L > \kappa\varepsilon \\ L/\kappa & L \le \kappa\varepsilon \end{cases}$$

$f_a = a/500 + f_y$
$f_z = f_y - b/200$

$$f_y = \begin{cases} (L + 16)/116 & y > \varepsilon \\ (\kappa y + 16)/116 & y \le \varepsilon \end{cases}$$

e = 0.008856
? = 903.3

Lab to LCH(ab) [8]

$L = L$
$C = (a^2 + b^2)^{1/2}$
$H = \tan^{-1}(b/a)$

LCH(ab) to Lab [8]

$L = L$
$a = C\cos H$
$b = C\sin H$

LCH(uv) to Luv [8]

$L = L$
$u = C\cos H$
$v = C\sin H$

Luv to LCH(uv) [8]

$L = L$
$C = (u^2 + v^2)^{1/2}$
$H = \tan^{-1}(v/u)$

Luv to XYZ [8, 14]

$X = (d - b) / (a - c)$

$$Y = \begin{cases} ((L+16))/116)^3 & L > \kappa\varepsilon \\ L/\kappa & L \le \kappa\varepsilon \end{cases}$$

$Z = Xa + b$

$a = 1/3((52L)/(u + 13Lu_0) – 1)$
$b = -5Y$
$c = -1/3$

$d = Y((39L)/(v + 13Lv_0) – 5)$
$u_0 = 4X_w / (X_w + 15Y_w + 3Z_w)$
$v_0 = 9Y_w / (X_w + 15Y_w + 3Z_w)$

e = 0.008856
? = 903.3

RGB to HSL [4]

{R, G, B} all in the range [0, 1]
max is the maximum value of {R, G, B}
min is the minimum value of {R, G, B}

d = max – min

$$H = \begin{cases} \text{undefined} & \max = \min \\ 60 * (G-B)/d & \max = R \\ 60 * (B-R)/d + 120 & \max = G \\ 60 * (R-G)/d + 240 & \max = B \end{cases}$$

N.B. H is measured in degrees and should be adjusted to the range [0, 360)

L = ½(max + min)

$$S = \begin{cases} 0 & \max = \min \\ (\max - \min)/2L & 0 < L \leq ½ \\ (\max - \min)(2-2L) & L > ½ \end{cases}$$

RGB to HSV [3, 12]

d = max – min

$$H = \begin{cases} \text{undefined} & \max = \min \\ 60 * (G-B)/d & \max = R \\ 60 * (B-R)/d + 120 & \max = G \\ 60 * (R-G)/d + 240 & \max = B \end{cases}$$

N.B. H is measured in degrees and should be adjusted to the range [0, 360)

$$S = \begin{cases} 0 & \max = 0 \\ 1 - \min/\max & \max \neq 0 \end{cases}$$

V = max

RGB to XYZ [8]

[X Y Z] = [r g b][M]

for each colour, C, in {R, G, B} and c in {r, g, b}

Typical:

c = C ?

sRGB:

$$c = \begin{cases} C/12.92 & C \le 0.04045 \\ ((C + 0.055)/1.055)^{2.4} & C > 0.04045 \end{cases}$$

? – gamma for RGB working space
[M] – (see Computing [M])

Spectral Data to XYZ [1, 11]

X = S I(?)x(?)
Y = S I(?)y(?)
Z = S I(?)z(?)

I(?) = Spectral power distribution
x(?), y(?), z(?) = CIE colour matching functions

xyY to XYZ[1]

X = xY/y
Y = Y
Z = (1-x-y)Y/y

XYZ to Colour Temperature [8]

Robertson's Method (as presented by 8)

XYZ to Lab [8, 9, 12]

White Point: (X_w, Y_w, Z_w)
L = 116 fy – 16
a = 500(fx – fy)
b = 200(fy – fz)

for each D in {X, Y, Z} and d in {x, y, z}

$$f_d = \begin{cases} d^{1/3} & d > \varepsilon \\ (\kappa d + 16)/\ 116 & d \le \varepsilon \end{cases}$$

$d = D/D_w$

e = 0.008856
? = 903.3

XYZ to Luv [8, 14]

$$L = \begin{cases} 116y^{1/3} - 16 & y > \varepsilon \\ \kappa y & y \le \varepsilon \end{cases}$$

$u = 13L(u - u_w)$
$v = 13L(v - v_w)$

$y = Y/Y_w$

$u = 4X / (X + 15Y + 3Z)$
$v = 9Y / (X + 15Y + 3Z)$
$u_w = 4X_w / (X_w + 15Y_w + 3Z_w)$
$v_w = 9Y_w / (X_w + 15Y_w + 3Z_w)$

e = 0.008856
? = 903.3

XYZ to RGB [8]

$[r\ g\ b] = [X\ Y\ Z][M]^{-1}$

for each colour, C, in {R, G, B} and c in {r, g, b}

Typical:
$C = c^{(1/?)}$
sRGB:

$$C = \begin{cases} 12.92c & c \le 0.0031308 \\ 1.055c^{(1.0/2.4)} - 0.055 & c > 0.0031308 \end{cases}$$

? – gamma for RGB working space
[M] – (see 'Computing [M]')

XYZ to xyY [1, 11]

$x = X/(X + Y + Z)$
$y = Y/(X + Y + Z)$
$Y = Y$

Additional Computations

Dominant Wavelength [10]

The dominant wavelength is the closest monochromatic wavelength with CIE colour coordinates on the line formed by connecting the white point and the test colour point and extending it to infinity in both directions.

Colorimetric Purity [13]

x = Euclidean distance from the test colour to the white point
y = Euclidean distance from the colour coordinates of the dominant wavelength to the white point
p_e = excitation purity
$p_e = x/y$

p_c = colorimetric purity
y_d = y-value of dominant wavelength
y_c = y-value of colour
$p_c = p_e * y_d / y_c$

RGB Saturation [5, 6]

Brightness = μ
$\mu = (R + G + B)/3$
Saturation = s
$s = (((R - \mu)^2 + (G - \mu)^2 + (B - \mu)^2)/3)^{1/2}$

CMYK [7]

RGB in range [0, 1]
C' = 1 – R
M' = 1 – G
Y' = 1 – B

K = min{C', M', Y'}

if K = 1,
C = M = Y = 0
otherwise
C = (C' – K)/(1 – K)
M = (M' – K)/(1 – K)
Y = (Y' – K)/(1 – K)

Delta E

?E is the Euclidean distance between the 2 colours. Each colour is treated as a 3-dimensional Lab coordinate.
For colour 1, (L_1, a_1, b_1), and colour 2, (L_2, a_2, b_2):
$?E = v((L_1 - L_{2)2} + (a_1 - a_2) + (b_1 - b_2))$

Data Sources

CIE 2 & 10 degree CMF

http://www.cvrl.org/cie.htm

White Points

http://en.wikipedia.org/wiki/White_point

RGB Working Spaces

http://brucelindbloom.com/

1931 CIE Chromacity Coordinates

http://www.cvrl.org/cie.htm

References & Sources

1. http://en.wikipedia.org/wiki/CIE_1931_color_space
2. http://www.cvrl.org/cmfs.htm
3. http://en.wikipedia.org/wiki/HSV_color_space
4. http://en.wikipedia.org/wiki/HSL_color_space
5. http://en.wikipedia.org/wiki/Saturation_(color_theory)
6. http://en.wikipedia.org/wiki/Brightness
7. http://en.wikipedia.org/wiki/CMYK
8. http://brucelindbloom.com/
9. http://www.colourware.co.uk/cpfaq/q3-21.htm
10. http://en.wikipedia.org/wiki/Dominant_wavelength
11. http://www.fourmilab.ch/documents/specrend/
12. http://www.cs.rit.edu/~ncs/color/t_convert.html#XYZ%20to%20CIELUV%20&%20CIELUV%20to%20XYZ
13. http://www.delta.dk/C1256ED600446B80/sysOakFil/i103/$File/I103%20Dominant%20Wavelength.pdf
14. http://www.cs.rit.edu/~ncs/color/t_convert.html#XYZ%20to%20CIELUV%20&%20CIELUV%20to%20XYZ

Appendix B: Advanced Illuminance Features Technical Specifications

Overview

This section provides the formulas and data used to calculate values in the advanced Illuminance Features dialog included with LUZCHEM's Spectroradiometer software.

Table Of Contents

Conversion of Power to Illuminance

Illuminance at an individual wavelength [1]

$F_? = 683 * I(?) V_?$

? = wavelength (nm)
$F_?$ = Illuminance at ? (mlx/m^2nm) – Standard Luminosity Function
I(?) = Power at ? (mW/m^2nm)
$V_?$ = Value of Luminous Efficacy Function at ?

Illuminance in a specified range [1]

$F = S I(?) V_?$

Lux to Foot-candle conversion

10.76 lx = 1 fc

Luminous Efficiency Function Sources:

2 degree Cone Photopic:

http://www.cvrl.org/database/text/lum/ssvl2e_1.htm

10 degree Cone Photopic:

http://www.cvrl.org/database/text/lum/ssvl10.htm

1924 CIE Photopic:

http://www.cvrl.org/

1974 CIE Photopic:

http://www.cvrl.org/

1988 CIE Photopic:

http://members.misty.com/don/photopic.html

1951 CIE Scotopic:

http://www.cvrl.org/database/data/lum/scvle_1.txt

References:

1. http://en.wikipedia.org/wiki/Luminosity_function